

DC Position Control System – Determination of Parameters and Significance on System Dynamics

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Abstract—Physical systems used for control applications require proper control methodologies to obtain the desired response. Controller parameters used in such applications have to be tuned properly for obtaining the desired response from the systems. Tuning controller parameters depends on the physical parameters of the systems. Therefore, the physical parameters of the systems have to be known. Number of techniques has been developed for finding the mechanical parameters of motors. But, no straightforward method has been established for estimating the parameters of the load so far. This paper presents a method of determining mechanical parameters viz. moment of inertia and friction coefficient of motor & load. This paper also stresses that load parameters have appreciable effect on the dynamic response of systems and have to be determined. A DC servo position control system is considered for applying the method. Moment of inertia and friction coefficient of the DC servo motor as well as load are determined using the method. It is evident that moment of inertia and friction coefficient can be determined for any load arrangement using the proposed method. Effect of load on the system dynamics is emphasized by considering the PID controller tuning. It is found that PID controller when tuned based on estimated load parameters could yield optimum response. This justifies that load parameters have to be determined for dynamic load variations.

Index Terms— Inertia, Friction, Back emf, PID controller

I. INTRODUCTION

Identification of parameters of any physical system plays a vital role to choose the parameters of controllers appropriately. This is essential to make sure that the system controlled satisfies the desired performance specifications. Over the years, a great deal of research has been carried out in the estimation of parameters of systems using genetic algorithms, fuzzy logic and neural networks. Inertia and Friction coefficient of motor alone were determined but that of load were not considered even though optimization, adaptive control and artificial intelligent techniques were used [1]-[5]. The importance of estimation of load parameters was emphasized in [6] but strategies for estimating inertia and friction of load were not highlighted. Even in precise applications such as position control, viscous friction of motor was estimated [7] but that of load was not at all taken into consideration. In [8], load model parameters were obtained using genetic algorithm but friction coefficient of motor was not at all considered. Tuning controller parameters demands proper estimation of physical parameters of systems. If controller tuning is done based on only motor parameters

without considering the load parameters [9]-[13], then such a system will not yield desired response in real time. Precision and accuracy are of utmost importance in tuning controller parameters to achieve the desired transient and steady state responses without sacrificing stability. Hence determination of mechanical parameters of motor and load by employing appropriate techniques is of utmost importance. The controller tuning was done taking into account mechanical parameters of motor as well as load in which inertia and friction are either already known or specified [14]-[19]. However, variation of load parameters under dynamic load variation was not accounted [14]-[19].

Most of the control applications employ motor and mechanical load arrangement. Hence, simple and standard strategies are the order of the day to compute the moment of inertia and friction coefficient of motor and load. So far, no simple strategies have been developed to estimate inertia and friction. Further, the effect of variation of these parameters with respect to dynamic load variation on the system behavior has not been highlighted so far. This paper presents a very simple and standard procedure to determine the moment of inertia and friction coefficient of DC motor and load under dynamic load variations. Moreover, the effect of load on the system behavior is also highlighted with suitable case studies under dynamic load variations.

II. DETERMINATION OF PARAMETERS

A. Importance of Estimation of Dynamic Parameters

Parameters of the DC servomotor such as torque constant K_t , back emf constant K_b , armature resistance R_a , armature inductance L_a , moment of inertia of motor and load J , friction coefficient of the motor and load B have to be estimated properly so that controller parameters can be properly tuned and the desired response can be achieved from the DC position control system. K_t , K_b , R_a and L_a do not vary with load and hence these values are determined using conventional method. However, J and B vary with respect to load as per the details given in the subsections C and D. Hence, their variations will have an effect on the dynamics of the system.

DC servomotor used for illustration of the determination of parameters has the ratings: 24V, 4A, 4000rpm, 12.6W! armature resistance (R_a) and 283mH armature inductance (L_a).

B. Determination of Torque Constant

In armature control method, the armature voltage and

hence the armature current are varied. Back emf is calculated using the expression

$$E_b = V_a - i_a R_a \quad (1)$$

The value of angular speed ω is determined from the value of measured speed N in rpm. Back emf is proportional to speed.

$$E_b = K_b \omega \quad (2)$$

The slope of the graph obtained by plotting the variation of back emf E_b against speed ω gives the value of K_b . The mechanical equivalent of electrical power and mechanical power are equal at steady state.

$$\omega T_e = E_b i_a \quad (3)$$

Electromagnetic torque T_e is proportional to armature current i_a . Therefore,

$$T_e = K_T i_a \quad (4)$$

where K_T is the torque constant. From “(2)”, “(3)” and “(4)”, it can be obtained that

$$K_b = K_T \quad (5)$$

Hence, Torque constant K_T is obtained from the slope of the graph obtained by plotting the variation of E_b against ω . DC servomotor with the ratings as already mentioned above is switched on at no load. The armature voltage and hence the armature current are varied by armature control method and the corresponding values of speed are noted. Values of ω and E_b are calculated at each armature voltage and current. They are tabulated in Table I. From the Table I, it can be found that K_T for the servomotor is 0.04 Nm/A.

TABLE I. ESTIMATION OF K_T

S.No.	V_a (V)	i_a (A)	Speed (rpm)	ω (rad/sec)	E_b (V)
1	24.2	0.277	4680	490.08	20.7
2	21.4	0.256	4100	429.35	18.17
3	18.4	0.229	3516	368.19	15.59
4	16	0.216	3030	317.3	13.27
5	13.6	0.193	2550	267.03	11.16
6	10.6	0.166	1981	208.07	8.5
7	7.6	0.137	1399	146.54	5.87
8	5.6	0.115	1004	105.13	4.151

C. Estimation of Friction Coefficient

The torque equation of the motor and load arrangement is given by

$$T_e = J \frac{d\omega}{dt} + B\omega \quad (6)$$

where J and B are inertia and friction coefficient of the arrangement respectively. When the speed is constant, the torque equation becomes

$$T_e = B\omega \quad (7)$$

From “(4)” and “(7)”,

$$B = \frac{K_T i_a}{\omega} \quad (8)$$

where i_a is the armature current measured at steady state for the given load current. Thus B is determined for the given

load current using “(8)”.

DC servomotor is switched on at no load. The motor is loaded in steps. At each load current, steady state values of armature current and speed are noted. B is determined at each load using “(8)”. These values are tabulated in Table II.

TABLE II. ESTIMATION OF B

S.No.	i_a (A)	Speed (rpm)	ω (rad/sec)	B (Nm-sec/rad)
1	0.277 (no-load)	4680	490.08	2.261e-05
2	0.512 (load 1)	4330	453.44	4.52e-05
3	0.738 (load 2)	3983	417.1	7.077e-05

D. Determination of Moment of Inertia

When the supply to the armature is switched off, motor speed reduces to zero from its steady speed. Hence, the torque equation becomes

$$J \frac{d\omega}{dt} + B\omega = 0 \quad (9)$$

The solution for “(9)” obtained using the steady state speed as the initial value of speed is expressed by

$$\omega = \frac{T_e}{B} e^{-(B/J)t} \quad (10)$$

When $t = \tau = J/B$, mechanical time constant of the motor, the motor speed reduces from steady state speed to 36.8% of steady state speed. The time taken for speed of the motor to reduce from steady state speed to 36.8% of steady state speed gives the mechanical time constant of the motor and load. From the time constant, the moment of inertia of the motor and load is given by,

$$J = B\tau \quad (11)$$

Thus the moment of inertia of motor and load J can be determined by substituting the values of B and mechanical time constant τ in “(11)”.

DC servomotor is run at no load and two different load currents. Armature current and speed are measured at each load current. Whenever the motor is switched off, speed response is captured on the Digital Storage Oscilloscope. Speed responses are captured at no load and other two load currents. They are shown in Fig. 1 and Fig. 2 respectively. From these responses, time taken (mechanical time constant) for the speed to drop from its steady state initial speed to 36.8% of its steady state initial speed is noted for no load and two different loads. J is determined for each case using “(11)”. These values are tabulated in Table III.

TABLE III. ESTIMATION OF J

i_a (A)	Speed (rpm)	Mechanical Time constant τ (sec)	J (Kg-m ²)
0.277 (no load)	4680	1	2.26e-05
0.512 (load 1)	4330	0.43	1.94e-05
0.738 (load 2)	3983	0.22	1.56e-05

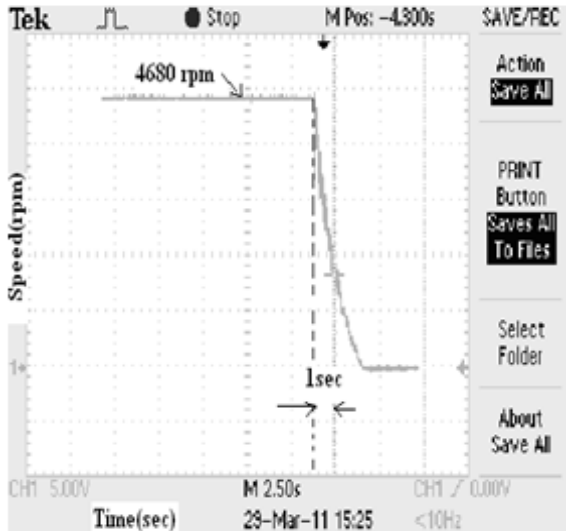


Figure 1. Speed response at no load

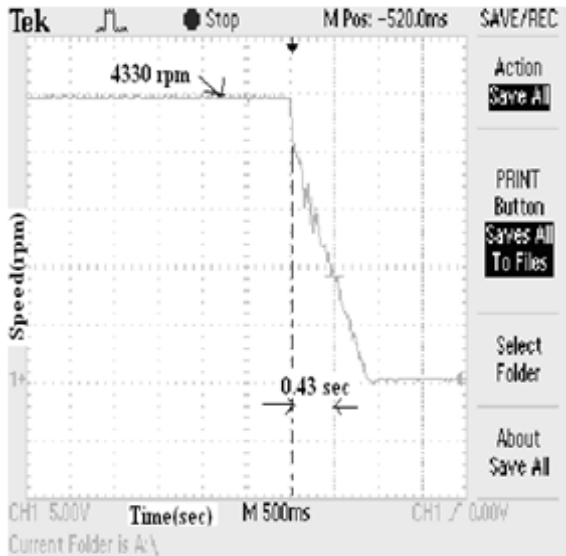


Figure 2. Speed response at load 1

III. EFFECT OF LOAD ON CONTROLLER TUNING AND SYSTEM DYNAMICS

DC position control system is considered for this analysis. Block diagram of DC motor used in position control is shown in Fig. 3. Transfer function of the DC position control system [20] is given by

$$\frac{\theta(s)}{V_a(s)} = \frac{K_T}{s[(R_a + sL_a)(Js + B) + K_b K_T]} \quad (12)$$

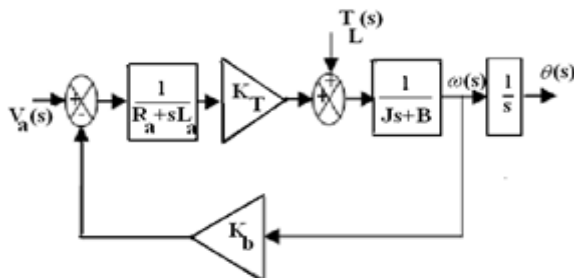


Figure 3. Block diagram of DC Motor

Transfer function of DC position control system at no load is obtained by substituting the estimated parameters of DC servomotor and load arrangement in “(12)”. It is given by

$$\frac{\theta(s)}{V_a(s)} = \frac{0.04}{s[(12.6 + 0.283s)(2.26e - 5s + 2.261e - 5) + 0.0016]}.$$

Using the above expression, step response of the DC position control system is determined by MATLAB simulation and shown in Fig. 4. Transfer function of DC position control system at load 1 is obtained as

$$\frac{\theta(s)}{V_a(s)} = \frac{0.04}{s[(12.6 + 0.283s)(1.94e - 5s + 4.52e - 5) + 0.0016]}.$$

Using the above expression, step response of the DC position control system is determined by MATLAB simulation and shown in Fig. 5. From Fig. 4 and Fig. 5, it is very clear that the response of DC position control system depends on the load current. These simulation results are shown in Table IV. From the Table IV, it is clear that the performance specifications depend on the load current. Hence, apart from mechanical parameters viz. inertia and friction of motor, mechanical parameters of the load also have to be determined for evaluating the response.(i.e. Inertia and friction of the load get added to that of motor to obtain the net inertia of the motor and load arrangement).

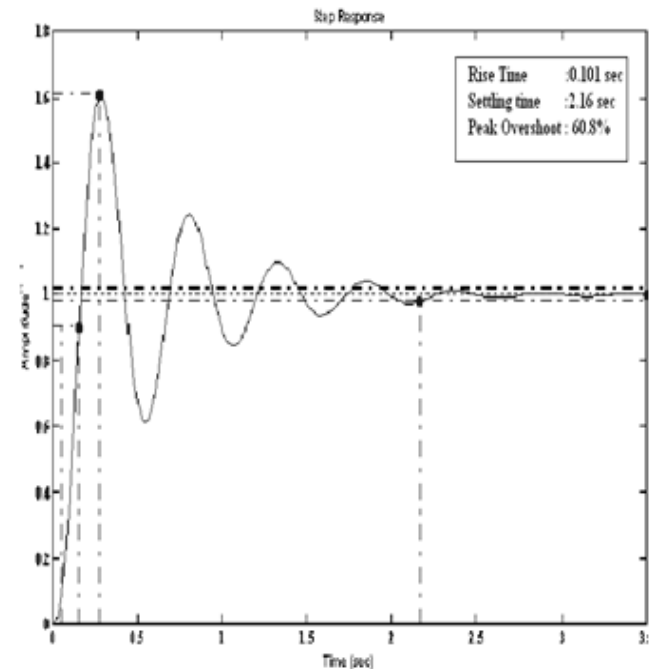


Figure 4. Step response of position control system at no load

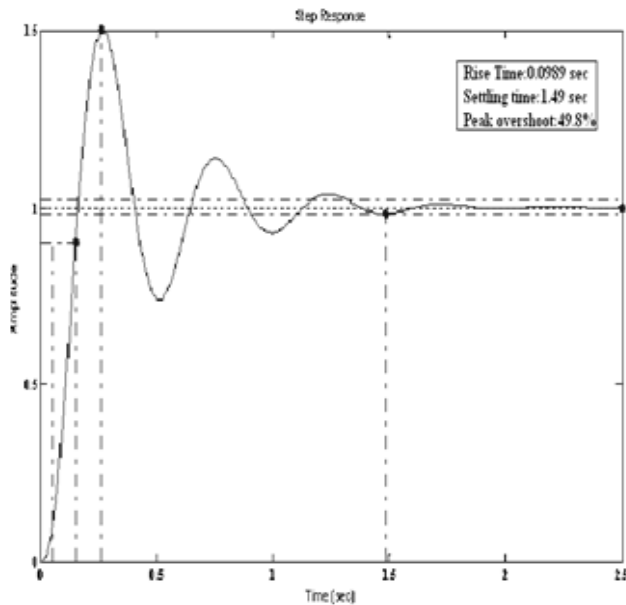


Figure 5. Step response of position control system at load 1

TABLE I. SIMULATION RESULTS OF DC POSITION CONTROL SYSTEM

Load setting	Rise Time (sec)	Settling Time (sec)	Peak Overshoot (%)	Steady State Output
No load	0.101	2.16	60.8	1
Load 1	0.0989	1.49	49.8	1
Load 2	0.0962	0.941	36.8	1

Response of the DC position control system with the use of PID controller is optimised at no load by PARR tuning [21] and shown in Fig. 6. Response of the DC position control system with the use of PID controller is optimised at load 1 and shown in Fig. 7. Response of the DC position control system with the use of PID controller is optimised at load 2 and shown in Fig. 8. These results are tabulated in Table V. From the Table V, it is clear that PID controller parameters are different at different load currents and have to be tuned based on the mechanical parameters of the motor and load at a particular load setting.

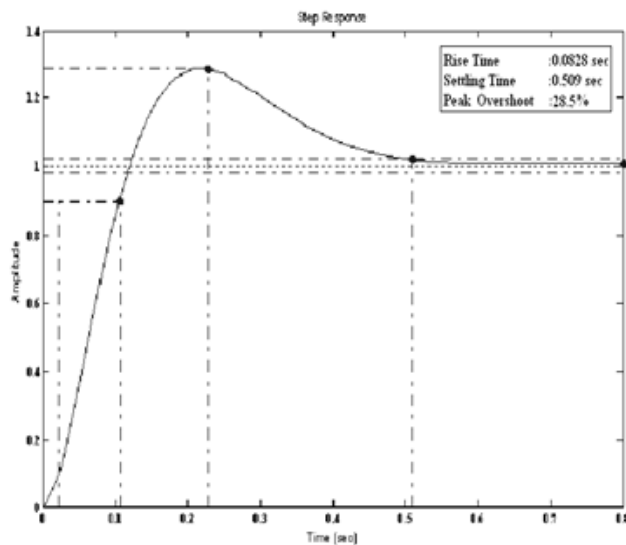


Figure 6. Step response of PID controlled system at no load

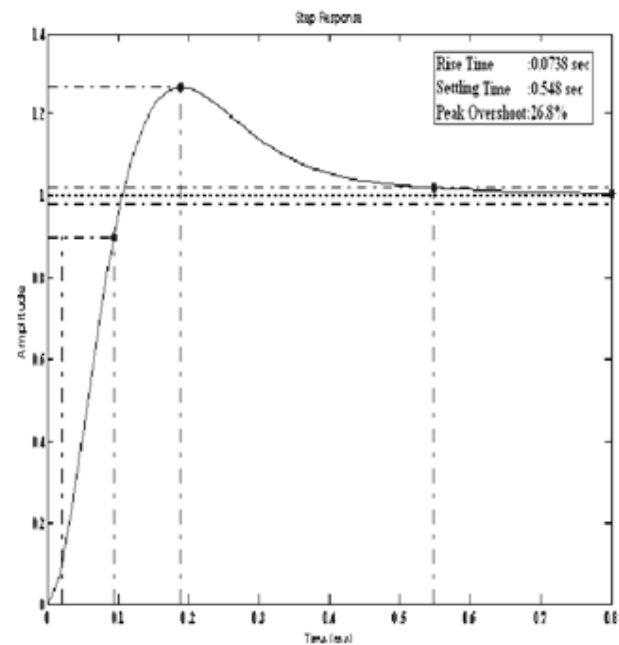


Figure 7. Step response of PID controlled system at load 1

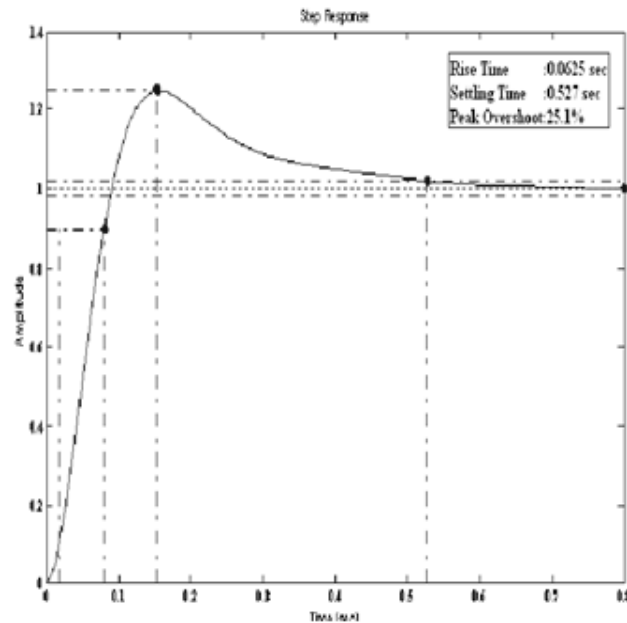


Figure 8. Step response of PID controlled system at load 2

TABLE V. SIMULATION RESULTS OF PID CONTROLLED DC POSITION CONTROL SYSTEM

Load setting	PID Controller Parameters			Rise Time (sec)	Settling time (sec)	Peak Over shoot (%)
	K_p	$T_d(\text{sec})$	$T_i(\text{sec})$			
No load	1.06	0.0735	0.3673	0.0828	0.509	28.5
Load 1	1.24	0.0638	0.3188	0.0738	0.548	26.8
Load 2	1.515	0.0530	0.2650	0.0625	0.527	25.1

Analysis of the simulation results from Table IV and Table V clearly reveal that load has effect on system dynamics because mechanical parameters J and B depend on the load setting and have to be accurately determined for evaluating the system response and tuning the controller parameters.

CONCLUSIONS

Proposed method can be used for estimation of moment of inertia and friction of DC motor and load under dynamic load variations. From the illustrative studies made on DC servo motor, it is found that inertia and friction of motor and load can be accurately determined using the proposed method. From the study of effect of load on the performance of DC position control system, it is found that these parameters have to be determined for any change in load and controller parameters have to be tuned accordingly.

This method can be extended to on-line parameter estimation of inertia and friction of DC motors with any type of load arrangement. There is no need to have information about inertia and friction well in advance. Further, controller parameters can be tuned from estimated parameters of inertia and friction of motor and load by employing artificial intelligent techniques. This will improve the response of the system in real time whenever there is a change in load.

This method can be also extended to on-line parameter estimation of inertia and friction of induction and synchronous motors with any type of load arrangement, if torque equation of DC motor is replaced by that of induction or synchronous motor.

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